

UNITED STATES PATENT APPLICATION
FOR
METHOD AND APPARATUS FOR PROVIDING IPSELATERAL THERAPY
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DESCRIPTION OF THE INVENTION

Field of the Invention

[001] The present invention relates to medical devices, and in particular, to methods, devices, and systems for controlling contraction of a heart.

Background

[002] During a normal heart beat, the heart contracts in a coordinated fashion to pump blood. In particular, the heart contracts based on rhythmic electrical impulses, which are spread over the heart using specialized fibers. These rhythmic electrical pulses are initiated by the heart's natural pacemaker called the sino-atrial node (SA node). In a normal heart there is a main pathway for the electrical current, which passes from the upper part of the heart (the atria) to the lower part (the ventricles). First, the SA node initiates electrical impulses to cause the right and left atria to contract. As the atria contract, the electrical impulses from the SA node propagate to the atrial-ventricular node ("AV node"). The time these impulses take to propagate from the SA node through the AV node is known as the A-V delay. The A-V delay allows the atria to fully contract and fill the ventricles with blood. The AV node then transmits a second impulse, which causes contraction in the right and left ventricles. Blood from the ventricles then flows out of the heart and to the rest of the body. Therefore, the heart relies upon a rhythmic cycle of electrical impulses to pump blood efficiently.

[003] A heart, however, may have cardiac defects that interfere with the rhythmic cycle or conduction of electrical impulses. For example, there are types of

cardiac deficiencies that cause early stimulation and contraction in the heart. Such pre-excitation deficiencies exist, for example, where the ventricles are activated by the impulse originating from the atrium at a time earlier than would be expected if the impulse reached the ventricles by way of the normal conduction system described above. For example, the Wolff-Parkinson-White syndrome is characterized by early stimulation and contraction of the ventricles. In Wolff-Parkinson-White syndrome, there is an accessory conducting pathway that leads from the atria to the ventricles. This pathway may at times encourage a rapid rhythm. In particular, instead of allowing the next heart beat to begin at the SA node, the extra pathway can pick up an electrical impulse in the ventricles and send it back upward to the atria. When this happens, the impulse begins to travel abnormally in a rapid, circular manner, causing a rapid heart rate.

[004] As noted above, a normal heartbeat includes an optimum A-V delay period to allow the atria to fully contract and fill the ventricles with blood. Cardiac defects, such as Wolff-Parkinson-White, cause early stimulation and contraction of the ventricles before the end of the A-V delay period, and thus, decrease the efficiency of the heart and may lead to heart failure.

[005] Unfortunately, known stimulation devices, such as artificial pacemakers, cannot compensate for such early stimulation in the heart. While Wolff-Parkinson-White syndrome may be controlled by certain drugs or through a procedure known as catheter ablation, known implantable devices only apply stimulating pulses to assist contraction in the heart and are unable to compensate for early stimulation, such as in Wolff-Parkinson-White syndrome. Accordingly, it

would be desirable to provide methods, apparatus, and systems, which can overcome these and other deficiencies in the prior art, for example, to assist the heart in contracting in a coordinated fashion.

SUMMARY OF THE INVENTION

[006] In accordance with an aspect of the present invention, methods and apparatus are provided for controlling contraction of a heart. Signals indicating electrical activity of sinus rhythm at a portion of the heart are received. An event is detected in the electrical activity at the portion of the heart. When the electrical activity at an additional portion of the heart reaches a threshold within a predetermined period of time of the event, contraction is suppressed in the additional portion of the heart based on when the electrical activity reaches the threshold.

[007] In accordance with another aspect of the present invention, a system controls contraction of a heart. At least one sensing element is configured to receive signals indicating electrical activity of sinus rhythm from the heart. A processor is coupled to the at least one sensing element and configured to detect an event in the electrical activity. The processor provides a control signal based on when the electrical activity reaches a threshold within a predetermined period of time of the event. A signal generator is coupled to the processor and provides an electrical signal suppressing contraction in a portion of the heart responsive to the control signal.

[008] In accordance with another aspect of the present invention, methods and apparatus are provided for controlling contraction of a heart. Signals indicating electrical activity of sinus rhythm at a portion of the heart are received. An event is

detected in the electrical activity. Contraction is then suppressed in the additional portion of the heart for a predetermined period of time from the detected event.

[009] In accordance with another aspect of the present invention, a system controls contraction of a heart. At least one sensing element is configured to receive signals indicating electrical activity of sinus rhythm from at least a portion of the heart. A processor is coupled to the at least one sensing element and configured to detect an event in the electrical activity. The processor provides a control signal in response to the detected event. A signal generator is configured to then provide an electrical signal to suppress contraction in an additional portion of the heart for a predetermined period of time from the event in response to the control signal.

[010] In accordance with another aspect of the present invention, methods and apparatus are provided for controlling contraction of a heart. Signals that indicate electrical activity of sinus rhythm are received from the heart. Contraction of a first chamber of the heart is suppressed based on the received signals. When the electrical activity at a second chamber of the heart reaches a threshold, the suppression of contraction of the first chamber ceases.

[011] In accordance with another aspect of the present invention, a system controls contraction of a heart. At least one sensing element is configured to receive signals indicating electrical activity of sinus rhythm of the heart. A processor is coupled to the at least one sensing element. The processor is configured to determine when a first chamber of the heart is contracting, and provides a control signal based on when the electrical activity of a second chamber of the heart reaches a threshold. A signal generator is coupled to the processor and selectively

provides an electrical signal that suppresses contraction in the first chamber of the heart in response to the control signal.

[012] Additional features and advantages of the invention will be set forth in part in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The features and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the appended claims.

[013] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

[014] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and together with the description, serve to explain the principles of the invention.

[015] In the figures:

[016] Fig. 1 illustrates an environment in which methods, apparatus, and systems may be applied consistent with the principles of the present invention;

[017] Fig. 2A illustrates electrical activity of sinus rhythm associated with a normal heartbeat;

[018] Fig. 2B illustrates electrical activity of sinus rhythm associated with a heart suffering from Wolff-Parkinson-White syndrome;

[019] Fig. 3 illustrates a functional block diagram of a controller for controlling contraction of a heart consistent with the principles of the present invention;

[020] Fig. 4 illustrates a method of controlling contraction of a heart consistent with the principles of the present invention; and

[021] Fig. 5 illustrates another method of controlling contraction of a heart consistent with the principles of the present invention.

DESCRIPTION OF THE EMBODIMENTS

[022] Methods, apparatus, and systems are provided to control contraction of the heart. At least one sensing element receives signals indicating electrical activity of sinus rhythm of the heart. The electrical activity is monitored and analyzed to detect an event. In addition, the electrical activity is monitored to detect when the electrical activity reaches a threshold within a predetermined period of time from the event. Contraction in the heart is then suppressed using, for example, one or more electrical pulses. In addition, after another predetermined period of time, the heart may then be allowed to contract naturally, or a stimulating pulse may be applied to assist the heart in contracting.

[023] Reference will now be made in detail to exemplary embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

[024] Fig. 1 illustrates an environment in which methods, apparatus, and systems may be applied consistent with the principles of the present invention. As

shown, a controller 104 may accompany a heart 102. In addition, heart 102 is shown with a superior vena cava 106, a right atrium 108, a left atrium 110, a right ventricle 112, a left ventricle 114, a sino-atrial node ("SA node") 116, an atrial-ventricular node ("AV node") 118, a Bundle of His 120, a right bundle branch 122, a left bundle branch 124, and Purkinje fibers 126.

[025] Heart 102 normally contracts in two stages based on sinus rhythm. Sinus rhythm is where heart 102 contracts in response to electrical impulses generated from SA node 116. In order to cause contraction in the cardiac muscle of heart 102, the electrical impulses from SA node 116 must depolarize the muscle fibers above a threshold voltage of approximately -80 mV.

[026] Accordingly, as the electrical impulses propagate from SA node 116 to AV node 118, right atrium 108 and left atrium 110 contract. Typically, the electrical impulses take approximately 120 to 200 milliseconds to travel from SA node 116 to AV node 118 (i.e., an AV delay of 120 to 200 milliseconds) and allow right ventricle 112 and left ventricle 114 to fill with blood.

[027] Once the electrical impulses propagate to AV node 118, AV node 118 then emits an electrical impulse. This electrical impulse propagates relatively quickly over heart 102 down Bundle of His 120, and over right bundle branch 122, left bundle branch 124, and Purkinje fibers 126. In response, cardiac muscles in right ventricle 112 and left ventricle 114 depolarize and contract to pump blood to the rest of the body (not shown).

[028] Controller 104 assists heart 102 to contract in a coordinated fashion. For example, controller 104 may apply one or more electrical pulses that suppress

or stimulate contraction in the cardiac muscle of heart 102 as needed. As noted above, in order to contract, cardiac muscle in heart 102 must be depolarized above a threshold voltage of approximately -80 mV. In addition, when recovering from contraction, the cardiac muscle repolarizes to a resting voltage of approximately -90 mV. Thus, controller 104 may selectively suppress or stimulate contraction in heart 102 by applying electrical pulses to repolarize or depolarize the cardiac muscle. In general, cathodal electrical pulses tend to stimulate contraction while anodal electrical pulses tend to suppress contraction.

[029] Controller 104 may be coupled to heart 102 using a lead 128. Lead 128 may be installed endocardially into heart 102 via superior vena cava 106 using known surgical procedures. Lead 128 may be implemented as a hollow catheter made of an insulating material, such as silicone rubber, and provide a plurality of connection paths for carrying signals representing electrical activity of heart 102 and carrying electrical signals, such as electrical pulses, from controller 104. For example, lead 128 may further include an atrial lead branch 130, an atrial electrode 132, a right ventricle lead branch 134, a right ventricle electrode 136, a left ventricle lead branch 138, and a left ventricle electrode 140. Alternatively, controller 104 may be coupled to heart 102 using a plurality of leads. The leads may be endocardial, epicardial, or subcutaneous.

[030] Atrial lead branch 130 provides a connection path between controller 104 and right atrium 108 for carrying signals associated with right atrium 108 and SA node 116 and electrical signals from controller 104. Although atrial lead branch 130

is shown integrated within lead 128, atrial lead branch 130 may also be implemented using a separate lead from controller 104.

[031] Atrial electrode 132 senses electrical activity in heart 102 associated with right atrium 108 and SA node 116 and delivers electrical signals from controller 104. Atrial electrode 132 may be implemented, for example, as a helical coil of wire made of a metal, such as stainless steel. Although a single electrode is shown, a plurality of electrodes may be implemented with atrial electrode 132.

[032] Right ventricle lead branch 132 provides a connection path for carrying signals associated with right ventricle 112 and providing electrical signals from controller 104 to right ventricle 112. Although right ventricle lead branch 134 is shown integrated within lead 128, right ventricle lead branch 134 may also be implemented using a separate lead from controller 104.

[033] Right ventricle electrode 136 senses electrical activity in heart 102 associated with right ventricle 112, such as electrical impulses from AV node 118 and propagating over right bundle branch 122. Right ventricle electrode 136 may also be implemented, for example, as a helical coil of wire made of a metal, such as stainless steel. In addition, a plurality of electrodes may be implemented with right ventricle electrode 136.

[034] Left ventricle lead branch 138 provides a connection path for carrying signals associated with left ventricle 114 and providing electrical signals from controller 104 to left ventricle 114. Although left ventricle lead branch 138 is shown integrated within lead 128, left ventricle lead branch 138 may also be implemented using a separate lead from controller 104.

[035] Left ventricle electrode 140 senses electrical activity in heart 102 associated with left ventricle 114, such as electrical impulses from AV node 118 and propagating over left bundle branch 124. Left ventricle electrode 140 may also be implemented, for example, as a helical coil of wire made of a metal, such as stainless steel. In addition, a plurality of electrodes may be implemented with left ventricle electrode 140.

[036] Fig. 2A illustrates electrical activity of sinus rhythm associated with a normal heartbeat. A waveform 200 shows one cycle of sinus rhythm and comprises a plurality of events including a P-wave 202, a QRS complex 204, and a T-wave 206. P-wave 202 indicates electrical activity that coincides with the spread of electrical impulses from SA node 116 over right atrium 108 and left atrium 110 and the contraction of these chambers. Typically, P-wave 202 has an amplitude of 0.1 mV and a duration of approximately 0.1 seconds.

[037] QRS complex 204 indicates electrical activity that coincides with the spread of electrical impulses over right ventricle 112 and left ventricle 114 and the contraction of these chambers. Typically, QRS complex 204 occurs approximately 0.2 seconds after P-wave 202. In addition, QRS complex 204 typically has an amplitude of approximately 1 mV and a duration of approximately 0.08 seconds.

[038] T-wave 206 indicates electrical activity that coincides with the recovery of right ventricle 112 and left ventricle 114 from contraction. Typically, T-wave 206 occurs approximately 0.2 seconds after QRS complex 204. In addition, T-wave typically has an amplitude and duration twice that of P-wave 202, i.e., approximately 0.2 mV and 0.2 seconds.

[039] Fig. 2B illustrates electrical activity of sinus rhythm associated with a heart suffering from Wolff-Parkinson-White syndrome. Similar to waveform 200, a waveform 208 comprises P-wave 202, QRS complex 204, and T-wave 206. However, due to Wolff-Parkinson-White syndrome, waveform 208 also shows a region of premature electrical activity 210 between P-wave 202 and QRS complex 204. Premature electrical activity 210 may, for example, cause premature stimulation and contraction of right ventricle 112 and/or left ventricle 114. Although Wolff-Parkinson-White syndrome is illustrated in Fig. 2B, other types of cardiac defects, such as other types of pre-excitation defects, may be treated in accordance with the principles of the present invention.

[040] Fig. 3 illustrates a functional block diagram of controller 104 for controlling contraction of heart 102 consistent with the principles of the present invention. As shown, controller 104 includes sense amplifiers 300, 302, and 304, a processor 306, a memory 308, a telemetry module 310, and a signal generator 312.

[041] Sense amplifiers 300, 302, and 304 are coupled to atrial electrode 132, right ventricle electrode 136, and left ventricle electrode 140. Sense amplifiers 300, 302, and 304 receive signals indicating electrical activity of heart 102 from their respective electrodes, amplify these signals, and provide them to processor 306. Sense amplifiers 300, 302, and 304 may be implemented using, for example, well known circuitry.

[042] Processor 306 receives and monitors signals from sense amplifiers 300, 302, and 304 and generates a control signal. For example, in order to treat Wolff-Parkinson-White syndrome, processor 306 may monitor the signals from

sense amplifiers 300, 302, and 304 to detect when the electrical activity of heart 102 indicates premature stimulation of a ventricle, such as from premature electrical activity 210. Processor 306 may detect the possibility of premature contraction of a portion of the heart based on a variety of parameters. For example, processor 306 may monitor the electrical activity of heart 102 during sinus rhythm and detect when the electrical activity in a ventricle reaches a threshold level, such as 0.07 mV or 0.1 mV, within a predetermined period of time, such as 0.1 seconds, from P-wave 202. Processor 306 preferably detects premature contraction in a ventricle or atrium before the ventricle or atrium receives a level of stimulation after which suppression of contraction could not occur. The threshold level may be modified as required to ensure that the detection of premature stimulation occurs in time to suppress contraction. Processor 306 may use other parameters and values consistent with the principles of the present invention to detect pre-excitation of a ventricle or atrium. For example, processor 306 may detect premature stimulation based on detecting electrical activity in a portion of heart 102, detecting contraction of a portion of heart 102, detecting a rise in blood pressure, or detecting a change in impedance in a portion of heart 102. Processor 306 then provides a control signal to signal generator 312 based on the electrical activity of heart 102.

[043] Alternatively, processor 306 may be configured to provide the control signal to signal generator 312 automatically. For example, processor 306 may be configured to provide the control signal to signal generator 312 automatically upon detecting P-wave 202.

[044] Processor 306 may be implemented using known devices. For example, processor 306 may be implemented using a series of digital circuits. Alternatively, processor 306 may be implemented using a microprocessor, such as those manufactured by Intel Corporation.

[045] Memory 308 provides storage for information used by processor 306. For example, memory 308 may include instructions for configuring processor 306 and instructions for monitoring the electrical activity of heart 102. Memory 308 may be implemented using known types of memory, such as a random access memory and read-only memory.

[046] Telemetry module 310 provides diagnostic information indicating the performance of controller 104. For example, telemetry module 310 may transmit the signals received from sense amplifiers 300, 302, and 304, and signals generated by signal generator 312 via a radio link to another device, such as an external programmer (not shown). Telemetry module 310 may also collect and transmit other types of information. Telemetry module 310 may be implemented as a radio receiver/transmitter using a known radio frequency, such as 100 kHz.

[047] Signal generator 312 generates electrical pulses for treating heart 102 via lead 128. Signal generator 312 may direct electrical pulses to one or more sites in heart 102, such as in right ventricle 112 or left ventricle 114 respectively via right ventricle lead branch 134 and left ventricle lead branch 138. In addition, as noted above, lead 128 may include a plurality of electrodes at various sites in each chamber of heart 102. Accordingly, signal generator 312 may also direct electrical pulses to one or more specific sites in each chamber of heart 102. Furthermore,

signal generator 312 may be coupled to heart 102 via a plurality of leads in addition to lead 128.

[048] Signal generator 312 may generate one or more electrical pulses to suppress contraction in heart 102 and compensate for premature stimulation, such as from premature electrical activity 210. In particular, signal generator 312 may generate an anodal electrical pulse of approximately 5 volts and with a duration of approximately 2-4 milliseconds to suppress contraction in heart 102. However, signal generator 312 may use other types of pulses, such as biphasic pulses, which can also be configured to suppress contraction in heart 102. For example, signal generator 312 could use pulses of the type disclosed in U.S. Patent No. 5,871,506, entitled "AUGMENTATION OF ELECTRICAL CONDUCTION AND CONTRACTILITY BY BIPHASIC CARDIAC PACING," U.S. Patent No. 6,067,470, entitled "SYSTEM AND METHOD FOR MULTIPLE SITE BIPHASIC STIMULATION TO REVERT VENTRICULAR ARRHYTHMIAS", U.S. Patent No. 6,411,845, entitled "SYSTEM AND METHOD FOR MULTIPLE SITE BIPHASIC STIMULATION TO REVERT VENTRICULAR ARRHYTHMIAS," U.S. Patent No. 6,141,587, entitled "AUGMENTATION OF MUSCLE CONTRACTILITY BY BIPHASIC STIMULATION," U.S. Patent No. 6,136,019, entitled "AUGMENTATION OF ELECTRICAL CONDUCTION AND CONTRACTILITY BY BIPHASIC CARDIAC PACING ADMINISTERED VIA THE CARDIAC BLOOD POOL," U.S. Patent No. 6,141,586, entitled "METHOD AND APPARATUS TO ALLOW CYCLIC PACING AT AN AVERAGE RATE JUST ABOVE THE INTRINSIC HEART RATE SO AS TO MAXIMIZE INOTROPIC PACING EFFECTS AT MINIMAL HEART RATES," U.S.

Patent No. 6,178,351, entitled "ATRIAL SENSING AND MULTIPLE SITE STIMULATION AS INTERVENTION MEANS FOR ATRIAL FIBRILLATION," U.S. Patent No. 6,343,232, entitled "AUGMENTATION OF MUSCLE CONTRACTILITY BY BIPHASIC STIMULATION," U.S. Patent No. 6,341,235, entitled "AUGMENTATION OF ELECTRICAL CONDUCTION AND CONTRACTILITY BY BIPHASIC CARDIAC PACING VIA THE CARDIAC BLOOD POOL," U.S. Patent No. 6,337,995, entitled "ATRIAL SENSING AND MULTIPLE SITE STIMULATION FOR ATRIAL FIBRILLATION," U.S. Patent No. 6,332,096, entitled "AUGMENTATION OF ELECTRICAL CONDUCTION AND CONTRACTILITY BY BIPHASIC CARDIAC PACING," and U.S. Patent No. 6,295,470, entitled "ANTITACHYCARDIAL PACING," all incorporated herein by reference.

[049] In addition, signal generator 312 may vary the electrical pulses delivered to heart 102 to control the suppression of contraction. Signal generator 312 may vary the number of pulses, the pulse amplitude, and pulse width. For example, signal generator 312 may generate multiple pulses to suppress contraction in heart 102 for a longer period of time than if a single pulse were used. Alternatively, signal generator 312 may increase pulse amplitude and duration to increase the period of time contraction is suppressed in heart 102.

[050] After one or more suppression pulses from signal generator 312 are applied to the pre-excited area of heart 102 (e.g., left ventricle 114) additional suppression pulses may be applied if necessary. For example, processor 306 may determine that the right ventricle will not contract until after a standard A-V delay period causing signal generator 312 to continue to suppress contraction, for

example, of left ventricle 114 until such contraction can be coordinated with contraction of right ventricle 112. For example, the present invention may allow for delay of contraction of left ventricle 114 for as much as 40 milliseconds to allow right ventricle 112 and left ventricle 114 to contract in a coordinated manner, thereby improving the hemodynamic efficiency of heart 102. In addition, if the one or more suppression pulses from signal generator 312 would cause a longer delay than desired for optimum coordinated contraction of heart 102, signal generator 312 may apply one or more stimulation pulses following the application of the one or more suppression pulses. The present invention may also be used to treat premature contraction of right ventricle 112, right atrium 108, left atrium 110, or any desired combination of chambers. For example, signal generator 312 may apply one or more pulses that suppress contraction in right ventricle 112 in order to delay the contraction of right ventricle 112 and allow right ventricle 112 to contract in a coordinated manner with left ventricle 114.

[051] Furthermore, signal generator 312 may be configured to provide one or more electrical pulses to stimulate contraction in heart 102. For example, signal generator 312 may provide a cathodal pulse of 5 V for a duration of approximately 2 milliseconds to stimulate contraction in heart 102. Signal generator 312 may use other types of pulses, such as biphasic pulses or anodal pulses, to stimulate or suppress contraction in heart 102.

[052] Fig. 4 illustrates a method of controlling contraction of a heart consistent with the principles of the present invention. In stage 400, controller 104 receives signals indicating electrical activity of heart 102. For example, atrial

electrode 132, right ventricle electrode 136, and left ventricle electrode 140 may provide signals to sense amplifiers 300, 302, and 304, respectively. Sense amplifiers 300, 302, and 304 may then amplify these signals and provide them to processor 306. Processor 306 may then interpret these signals to determine the electrical activity of sinus rhythm for heart 102. In addition, processor 306 may store data from these signals in memory 306, for example, for transmission by telemetry module 310 to another device.

[053] In stage 402, processor 306 detects an event in the electrical activity. For example, processor 306 may monitor the electrical activity for P-wave 202. In addition, processor 306 may store information related to this event, such as time and amplitude of the event, in memory 308.

[054] In stage 404, processor 306 then detects whether the electrical activity exceeds a threshold, such as 0.07 or 0.1 mV, within a predetermined period of time, such as 0.1 seconds, from the event. If the electrical activity does not exceed the threshold within the predetermined period of time, processor 306 interprets this circumstance as a normal sinus rhythm and processing repeats at stage 400. However, if processor 306 detects that the electrical activity reaches the threshold within the predetermined period of time, then processor 306 may interpret this circumstance as premature stimulation in an area of heart 102, such as premature electrical activity 210 in left ventricle 114 and/or right ventricle 112.

[055] In stage 406, processor 306 provides a control signal to signal generator 312 to suppress contraction in heart 102. The control signal may specify specific sites in heart 102 and the type of electrical pulses used to suppress

contraction. For example, processor 306 may provide a control signal specifying either right ventricle 112, or left ventricle 114, or both. In addition, processor 306 may specify a pulse type, such as cathodal, anodal, or biphasic, a pulse width, and a pulse amplitude.

[056] In stage 406, in response to the control signal from processor 306, signal generator 312 applies one or more electrical pulses to heart 102 via lead 128. For example, signal generator 312 may send electrical pulses via lead 128 to right ventricle electrode 136 and/or left ventricle electrode 140.

[057] In stage 408, signal generator 312 completes the application of the electrical pulses suppressing contraction. Processor 306 may then monitor the electrical activity of heart 102 to determine its response and whether the electrical pulses were sufficient to compensate for the premature stimulation, for example, by premature electrical activity 210. If needed, based on the response of heart 102, processor 306 may direct signal generator 312 to apply additional electrical pulses to suppress contraction for an additional period of time. Upon completion of the suppressing electrical pulses, processor 306 may allow heart 102 to contract naturally. Alternatively, processor 306 may provide a control signal to signal generator 312 to subsequently stimulate one or more sites to assist contraction in heart 102. Processing then repeats again at stage 400.

[058] Fig. 5 illustrates another method of controlling contraction of a heart consistent with the principles of the present invention. In stage 500, controller 104 receives signals indicating electrical activity of heart 102. For example, atrial electrode 132, right ventricle electrode 136, and left ventricle electrode 140 may

provide signals to sense amplifiers 300, 302, and 304, respectively. Sense amplifiers 300, 302, and 304 may then amplify these signals and provide them to processor 306. Processor 306 may then interpret these signals to determine the electrical activity of sinus rhythm for heart 102. In addition, processor 306 may store data from these signals in memory 306, for example, for transmission by telemetry module 310 to another device.

[059] In stage 502, processor 306 determines whether suppression is required in one or more portions of heart 102 based on the received signals. For example, processor 306 may monitor the electrical activity of right ventricle 112 and left ventricle 114 and determine whether either ventricle will prematurely contract. Processor 306 may store information related to this premature contraction, such as the time and amplitude, in memory 308.

[060] Processor 306 may determine whether a chamber of heart 102, such as right ventricle 112 or left ventricle 114, will prematurely contract based on whether the electrical activity in that chamber exceeds a threshold, such as 0.07 or 0.1 mV, within a predetermined period of time of contraction of another chamber of the heart, such as the right atrium. If the electrical activity does not exceed the threshold within the predetermined period of time, processor 306 may interpret this circumstance as a normal sinus rhythm and processing repeats again at stage 500. However, if processor 306 detects that the electrical activity reaches the threshold within the predetermined period of time, processor 306 may interpret this circumstance as premature stimulation in portion of heart 102, such as premature

electrical activity 210 in left ventricle 114 and/or right ventricle 112. Processing may then flow to stage 504.

[061] Alternatively, processor 306 may determine whether a first chamber of heart 102, such as right ventricle 112, will prematurely contract based on whether the electrical activity in that chamber exceeds a threshold, such as 0.07 or 0.1 mV, prior to electrical activity in a second chamber, such as left ventricle 114, exceeding a threshold, such as 0.07 or 0.1 mV. If the respective electrical activity in the first and second chambers indicates coordinated contraction, processor 306 may interpret this circumstance as a normal sinus rhythm and processing repeats again at stage 500. However, if processor 306 detects that the timing of the electrical activity in the first chamber will cause uncoordinated contraction relative to the second chamber, processor 306 may interpret this circumstance as premature stimulation in the first chamber. Processing may then flow to stage 504.

[062] In stage 504, controller 104 suppresses contraction in the one or more portions of heart 102. In one embodiment, processor 306 provides a control signal to signal generator 312 to suppress contraction in heart 102. The control signal may specify specific sites in heart 102 and the type of electrical pulses used to suppress contraction. For example, processor 306 may provide a control signal specifying either right ventricle 112, or left ventricle 114, or both. In addition, processor 306 may specify a pulse type, such as cathodal, anodal, or biphasic, a pulse width, and a pulse amplitude.

[063] In response to the control signal from processor 306, signal generator 312 applies one or more electrical pulses to heart 102 via lead 128. For example,

signal generator 312 may send electrical pulses via lead 128 to right ventricle electrode 136 and/or left ventricle electrode 140.

[064] In stage 506, controller 104 determines whether to continue to suppress contraction in one or more portions of heart 102 based on the electrical activity of heart 102. For example, processor 306 may monitor the electrical activity of heart 102 to determine how heart 102 is responding to the suppression of contraction and determine when to cease suppressing contraction in heart 102.

[065] In one embodiment, processor 306 monitors the electrical activity of heart 102 to determine when the electrical activity of a non-suppressed portion of heart 102 reaches a threshold. For example, if controller 104 is suppressing premature contraction in left ventricle 114, then processor may detect when electrical activity in right ventricle 114 reaches a threshold. If the electrical activity of heart 102 has not reached the threshold, then this indicates that one or more portions of heart 102, such as left ventricle 114, still require suppression of contraction and processing repeats again at stage 504. If the electrical activity, for example, in right ventricle 114 reaches the threshold, then processing flows to stage 508.

[066] In stage 508, controller 104 ceases the suppression of contraction in the one or more portions of heart 102. In one embodiment, signal generator 312 ceases applying electrical pulses to suppress contraction in response to a control signal from processor 306. The control signal from processor 306 may be generated when the electrical activity in heart 102 exceeds a threshold. In addition, processor 306 may be configured to cease suppressing contraction after a delay period.

[067] Furthermore, upon ceasing suppression, processor 306 may allow heart 102 to contract naturally, or provide a control signal to signal generator 312 to subsequently stimulate one or more sites to assist contraction in heart 102. Processing then repeats again at stage 500.

[068] Other embodiments of the invention will be apparent to those skilled in the art from consideration of the specification and practice of the invention disclosed herein. It is intended that the specification and examples be considered as exemplary only, with a true scope and spirit of the invention being indicated by the following claims.